CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fire constitutes a large threat to life and property in urban and rural areas. It has an undesirable impact on people both directly, via injury through exposure to smoke or flame, and indirectly through property damage and impairment of the environment [1]. In 2011, a total of 5428 fires cases were reported in Malaysia; 80 fire deaths; thousands fire injuries; and 927 millions in property losses. To address these concerns, fire protection system or devices has been invented to reduce the fire damages. Researches have been done in order to better understand the main causes of structural fire. Detail analysis of fire incidents could provide useful information for planning of fire prevention and response activities in terms of risk identification, resource targeting and routing of fire personnel and equipment, allocation of preventative measures, and policy evaluation.

In Malaysia, fire safety regulation for buildings in Malaysia focused on the design and construction of sufficient life safety, fire prevention, fire protection and fire fighting facilities in new buildings. A fire door is one of fire protection device that is designed to restrict the spread of fire. The purpose of it is to delay and interrupt the spread of dangerous things such as smoke, toxic gasses and of course the fire itself from passing from one fire zone to another, allowing people more time to escape and intervention by firemen.

1.2 Problem Statement

Generally fire doors are made from materials, including timber, steel, gypsum and other fire-resistant materials [2]. Timber constitutes major components for fire resistance door. Timbers have long been recognized for their ability to maintain structural integrity while exposed to fire. Currently 80% of all hinged fire door in Malaysia are made from timber component. Timber that come from logging activities give negative impacts and cause harm to environment. By introducing possible waste materials composites that have similar fire resistance properties as timber, the uses of timber can be decreases. The problem statement for this project is lack of alternative material from waste have been widely used in the making of fire door. There is also lack of details or data of the fire resistance properties of the material from waste that can be used to replace the uses of timber in fire door makings. Therefore, studying the fire resistance of the material is needed and conducting fire test are compulsory in order to evaluate the fire resistance of the material.

1.3 Objectives

The objectives of the project are:

a) To develop any possible waste material that can suitable to be used in fire door making based on its fire resistance.

b) To study and manufacture fire-resistance composite plates using waste sawdust as filler, Portland cement as an inorganic binder.

c) To study the pattern of the temperature rise on the unexposed side of the composite plate when exposed to high temperature and compared with the original wood.

d) To study the effect of binder content and type of additive used to the fire resistance behavior of the composite.

1.4 Scope of Study

The scope of study for this project will be mainly related to the research on the possible waste materials that can replace the use of timber in the fire door, but not just limited to it. Fire resistance testing method will be performed, and the results of this testing method will be analyzed and discussed in order to identify the best solution material that met the objectives. The techniques learnt while in classes will be applied to produce the accurate and consistent result. Analysis of the results will be conducted at the end of the project, so that the project can be concluded as meeting the objectives or not. Suggestion and recommendations to improve the project from all aspect will be identified. There are limitations to the project that beyond the reach of me.

CHAPTER 2
LITERATURE REVIEW

2.1 Fire Resistance Door

Fire door also known fire resistance door is a set of door that have high fire resistance used as passive fire protection item within buildings to prevent the spread of fire or smoke which may consist of dangerous chemicals [2]. It is usually have two important functions in a fire; when closed they form a barrier to delay the spread of fire and when opened they provide a means of escape. A well designed fire door will delay the spread of fire and smoke without causing too much obstruction to the movement of people and properties. Every fire door is required to act as a barrier to the passage of smoke and fire to varying degrees depending on the location of the door in a building and the fire hazards related with that building. As one of a fire protection, it is required to present resistance to the passage of a well developed fire must be fitted with intumescent seals. These seals remain idle under normal conditions but expand greatly when there are present of heat from a fire to close the gap between the door and its frame. Dangerous smoke will be generated when there is a fire. Smoke from fire give even greater threat to human life and property than flames. Particularly in the early stages of a fire, fire doors should also be integrated with a ‘cold smoke’ seal to prevent the access of smoke around the door frames. A fire door system should have both combined smoke with intumescent seals to protect from all aspects of fire in a single unit [3].

Fire doors are manufactured in a wide variety of construction. Some of the common types are wood-core doors, steel doors and composite doors. The type of door and the way it is installed are important to make sure the standard degree of protection. Mostly fire doors manufactured in Malaysia are made of wood or lumber. Timber constitutes the major components for fire resistant door. Components such as door frame, internal membrane and plywood finisher are made of wood.Wood is composed of a mixture of cellulose, hemicellulose, and lignin bound together in a complex network. Large wood members have long been recognized for their ability to remain its structural integrity while bare to fire which proven it’s have high fire resistance. Fire Resistance is the capacity of a material to resist a fire, while still performing its structural function [4]. Fire Resistance periods are specified for different element to indicate how long they can stand without loss in function as loadbearing or prevention of fire spreading [5]. As the wood is exposed to fire, charring reduces the cross section of the member. In addition to charring of the wood member, the residual structural capacity is affected by the elevated temperature gradient within the uncharred wood [6]. The fire-resistive characteristics of exposed wood members are due to the insulative characteristics of the char layer and the sharp temperature gradient beneath the base of the char layer. As a result, even an unprotected structural wood member retains its structural stability in a fire for a period of time. [7]. Fire door may be classified by an hourly rating designation, an alphabetical letter designation, or a combination. Figure 2.1 below shows the assembly of standard fire door.

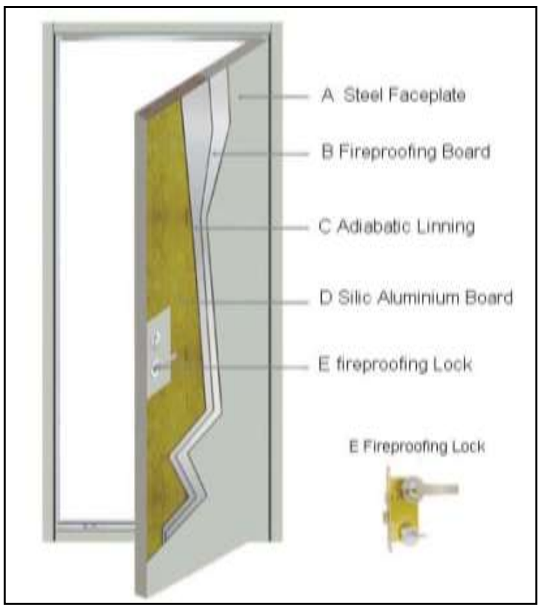

Figure 2.1: Fire Door Structure

2.2 Fire Resistant of materials

When materials or products are exposed to heat, the fire resistance of the materials can be identified. This property of materials is identified in term of the ease or difficulty of the material undergoes a transformation through several processes which are [13]:

- Softening and melting
- Decomposition, vaporization and charring
- Ignition
- Flame spread and fire growth
- Release of heat
- Release of smoke, toxic and corrosive compounds

These are the most serious stage and the main cause of fire hazards because of the release of heat, smoke and corrosive compounds. As a result, many standards test have been introduced to assess the flame spread, fire growth and peak burning behavior of materials and products [13].

For the element that is used in construction field, the fire resistance of an element is defined as a measure of ability to maintain it original structural in the effects of fire in one or more of the following ways:

- *Resistance to collapse*: that is, the ability to maintain loadbearing capacity.
- *Resistance to fire penetration*: that is, the ability to maintain the integrity of the element.
- *Resistance to the transfer of excessive heat*: that is, the ability to provide insulation from high temperature [14].

The fire resistance behavior of a material commonly characterized using the heat release rate parameter (HRR). The heat release rate (HRR) is the rate at which heat energy is evolved by a material when burned and is used to measure how large and how quickly a fire environment grows. Recently advances in fire research and fire dynamics have emphasized the importance of heat release rate as the primary fire hazard indicator of material [8]. The peak heat release rate (HRR) is the primary characteristic determining the size, growth, and suppression requirements of a fire environment.

2.3 Standard Test Method

There are variety of international standard tests are used to ensure the products are qualified for a particular application and meet the requirements. In the standard test methods of fire reaction behavior of materials, certain patterns are made for visual observations of any changes of flame movement and char during the test. Some specification also made for measurement of surface temperature and release rate of materials vapors, heat and chemical compounds, including smoke. All the standards small and large scale tests are conducted using the material and products [13]. The specimens of the test are different in standard size to meet the testing requirement. The fire resistance is generally highly depending on the thickness and in many applications for fire resistance panels [22].

In UK, The assessment of fire performance of materials is done according to procedures define in the BS 476 series. This standards series include test methods for both reaction to fire and fire resistance of the building materials and structures.

The most relevant standards that being used to assess the basic reaction to fire properties for innovative material is Parts 6 and 7 of the BS 476 series. This standard including the method of test dealing with fire propagation and surface spread flame [14].

Figure 2.3: Full-scale test furnace, National Research Council of Canada, Ottawa [30].

2.4 Biocomposite

Wood plastic composites (WPC) or biocomposites are new types of material that have a broad range of composites materials. It using an organic resin binder (matrix) and fillers made of cellulose materials. The new and rapidly developing biocomposite materials are high technology products, which have one unique advantage. The wood filler can include sawdust and scrap wood products. Thus, there are no additional wood resources are needed to produce biocomposites. Waste products such as wood scraps that originally cause money for a proper disposal activity now become a useful resource and can be recycling [8].

In use of biocomposites materials, one of the primary problems is the flammability of the two main components which are the organic binder and cellulose-based filler. Flame retardant will disturb the adhesion between fiber and matrix if it is added. It is hard to develop or produce a fire-resistant biocomposite and at same time maintain its level of mechanical properties [16]. Organic matrices can be used to improve the fire resistance properties of the composites. The inorganic matrix can resist temperatures up to 1000^{o}C and it provides protection to sawdust for short duration [21]. Inorganic binder systems such as gypsum and Portland cement have high resistance to fire and insects [15]. However, the main disadvantage of using this binder system is the maximum amounts of wood filler that can be integrated are low. This is due to the naturally high viscosity of the inorganic resin which prevents the ability of the sawdust particle to become fully saturated with resin during mixing process [8].

Certain criteria such as wood to cement ratio, size and shape of the wood particle give an impact on the strength and suitability of the composites [18]. Cement wood particle composites consisting of 20% wood by weight in which the wood of in the form of flakes of 10 to 30mm long and 0.2 to 0.3mm thick had densities ranging between 1200 to 1300 kg m^{-3} and bending strength from 10.1 to12.9 N mm^{-2} [19]. The proportion of wood had effect on the bending strength of cement bonded composite.

CHAPTER 3
METHODOLOGY / PROJECT WORK

3.1 Research Methodology

The main objective of this project is to study and manufacture fire-resistant composite plates using waste sawdust as filler and an inorganic binder system which is Portland cement. With the present of this material, the waste product can be recycled and the uses of lumber in making of fire doors can be reduced.

A thorough research was done through the internet and from the books from Information Resource Centre (IRC) on the material properties study and standard fire resistance test. Several reports that have similar objectives were also referenced to analyze the format and standard used to complete the project documentations.

3.2 Materials

3.2.1 Waste

Waste sawdust is used as filler to make the fire-resistant composite plates. In this project, waste sawdust that is used is based of *Neobalanocarpus heimii* (Cengal) collected from M.S. Zabki (M) Sdn. Bhd, Taman Perindustrian Perabot, Lahat, Perak. The sawdust particles are between 6.-7 mm in diameter. The reason why sawdust is choose to be used is because it is waste product, easy to be found and based on literature, the composite with sawdust filler has high fire resistance. Figure 3.2.1 shows the sample of sawdust used on this research.

Figure 3.2.1: Sample of sawdust used

3.2.2 Inorganic Binder

Portland cement is used in the manufacture of the plates as a binder. Ordinary Portland Cement (OPC) is the most common type of cement in general used in construction around the world, as a basic ingredient of concrete, mortar, stucco, and most non-specialty grout. It usually originates from limestone.

3.2.3 Additive

Vermiculite is primarily made of silicates of aluminum, iron and magnesium. It diameter ranges from 1mm to 1cm. This material commonly used in construction as a building insulation. It has a shiny surface structure which becomes a reflector of radiation that capable of disappear heat and increase the thermal insulation capacity of material that contains it [22]. All it properties make it suitable to become additive to increase the fire insulating capacity of the materials under study. Its diameter is between 8-10 mm.

Other additive that is used in this research is rubber particle. The rubber particle is come from automotive industry waste which is tyres. The material is grinded by grinding machine. The particle size is between 8 – 12 mm.

3.3 Composite Plates Preparation

Several panels or plates with different composition will be produced by using suitable manufacturing technique. This plate will be used as test specimen for fire testing. The plate will be fabricated in standard size to meet the testing requirement. The fire resistance is generally highly depending on the thickness and in many applications for fire resistance panels [22]. The thickness of the panel depends on the application of the material and in this case, the material will be used to replace the uses of timber in making a fire door. The mould of the plates was produced using wood plate to form the composite plate at the desired dimension. Before fabrication of plate is started, mass of each material is determined. The mass of material is determined by measuring the mass of cup carried the material first and then minus it with the mass of cup. Same cup will be used during the measuring process. Assuming that the mass of air is negligible, Table 3.3(a) shows the mass of each material used. Each plate is distinguished by varying the composition of each composite. Each composite contains different amount of material which is based on the number of cup. Table 3.3(b) shows the composition of each plate by number of cup with different material.

Portland cement was mixed with sawdust. Before the plate formation, the sawdust is soaked in water and then air-dried. The sawdust then mixed with the cement according to the percentage by mass. The percentage used was based on the literature before. After the mixture gets a consistence color, water will be added to the mixture. Volume of water added in each composite is constant. The mixture then were placed in a forming mould and pressed to provide the required compaction. The specimens were cured under shade at room temperature for three days in the mould and for another 20 days after removal from the mould. The plates produced in dimension of 150 mm x 150 mm by 15 mm thickness. Once the specimens have been produced, their masses were determined using weight scale and the densities of the plate were calculated from mass and volume of the plate and then will be tested on the fire resistance test.

Table 3.3(a): Mass of cup carried different material

No	Description	Mass (g)
1	Cup only	27.201
2	Cup + sawdust	33.202
3	Cup + Portland cement	48.200
4	Cup + Vermiculite	56.019
5	Cup + Rubber particle	36.202

Table 3.3(b): Composition of each plate by number of cup with different material.

Composite Plate	Number of cup with material			
	Sawdust	Cement	Additive	
			Vermiculite	Rubber
Plate A	2	2	-	-
Plate B	3	2	-	-
Plate C	2	3	-	-
Plate D	2	2	1	-
Plate E	2	2	-	1

Table 3.3(c): Mass of material composition for each plate

Composite Plate	Mass of material (g)			
	Sawdust	Cement	Additive	
			Vermiculite	Rubber
Plate A	12	42	-	-
Plate B	18	42	-	-
Plate C	12	63	-	-
Plate D	12	42	29	-
Plate E	12	42	-	9

Table 3.3(d): Percentages by mass of composite plate

Composite Plate	Percentages by mass (%)			
	Sawdust	Cement	Additive	
			Vermiculite	Rubber
Plate A	23	77	-	-
Plate B	31	69	-	-
Plate C	16	83	-	-
Plate D	17	48	35	-
Plate E	19	64	-	17

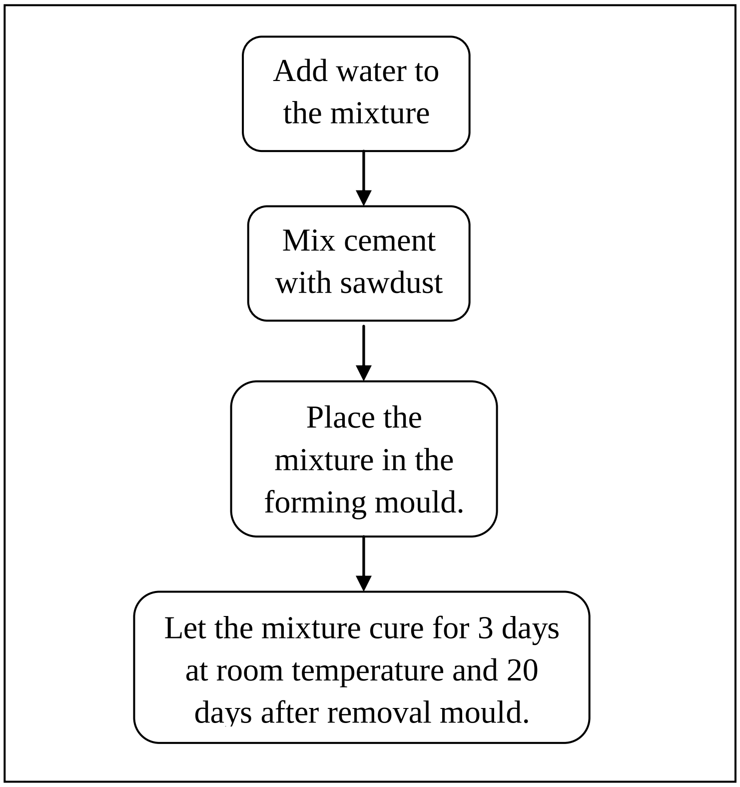

Figure 3.3 (a) Steps in preparing specimens

Another material that will be tested in the fire resistance test is original wood plate. Since wood is the major component in the fire door making, wood plate was used as reference material in order to compare the behavior of each plate against fire. Type of wood that will be tested is *Neobalanocarpus heimii* (Cengal). Since fire resistance of one material is highly depends on the thickness, the dimension of the plate must be same with the composite plates produced. Table below shows the percentage by mass of composite that is produced.

Figure 3.3(b): Curing process of the composite plates

3.4 Fire Resistance Test

The standard fire resistance test described in European regulations [6], which is widely used international standards, is the result of the observation and analysis of several actual fires. To stimulate the conditions of exposure to fire, the regulation requires that one side of the plate to be exposed to heat according to a standard temperature curve defined by the equation: $T = 20+345\log_{10}(8t+1)$, where T is the oven temperature for the tests in ^{o}C and t is the time in minutes from the beginning of the test[6].

Mostly, the heat flux is used in the standard fire resistance test. The heat flux is set to produce heat according to the standard temperature curve. Since the equipment is not available, alternative procedure and different equipment has been used. A butane gas cartridge is used to produce heat. Since it is hard to produce standard temperature curve using fire source from gas cartridge, the fire resistance test is done at a constant temperature. The specimens are tested at the constant temperature of 950 ^{o}C which is the highest temperature recorded by the standard temperature curve within 60 minutes. Figure 3.4(a) shows the temperature curve for standard fire testing and temperature used to heat the specimens in this fire testing.

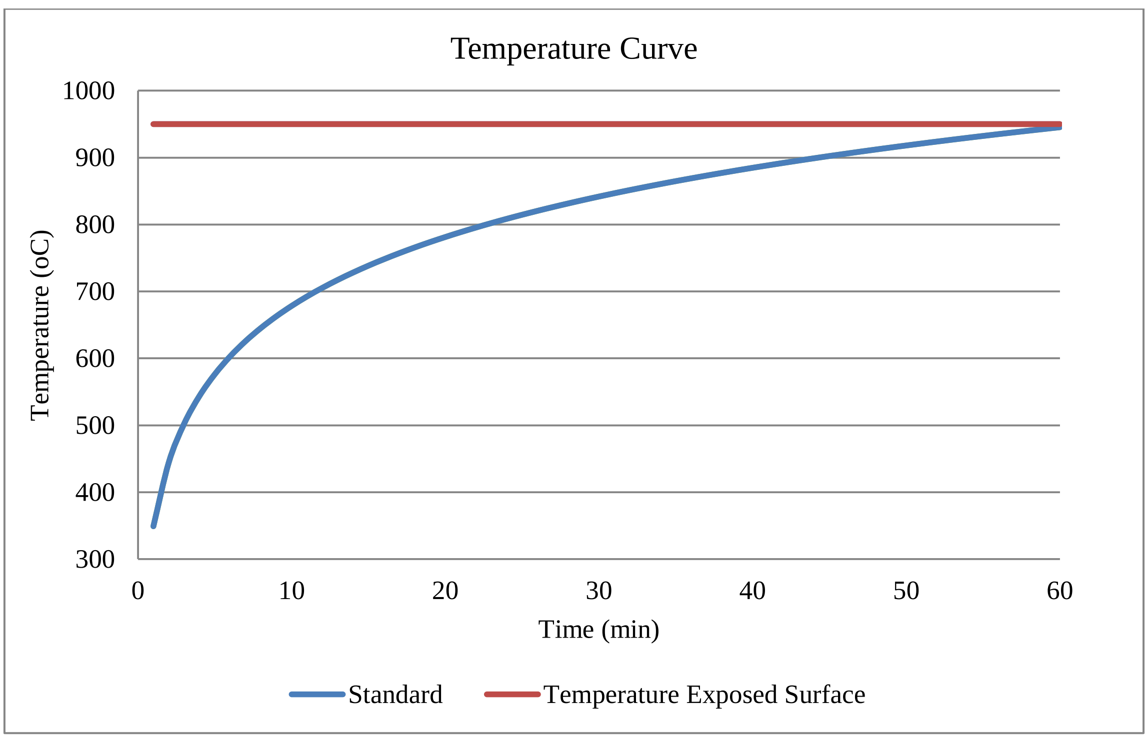

Figure 3.4(a): Standard Temperature and Temperature Curve on Exposed Surface

The test was carried out in a fume chamber in order to prevent the spread of smoke. Figure 3.4 (a) shows the setup of the fire resistance test. There are three thermocouple were used and were placed on the non-exposed surface in order to monitor its temperature rise. The temperature changes on the non-exposed surface were taken in every minute and plotted on the temperature vs. time graph.

In accordance with EN1363-1: 2000 standard [20], the completion of the test is produced by applying one of these two criteria:

- The temperature of one of the thermocouples on the non- exposed surface of the material is above180 ^{o}C.
- The average temperature of all the thermocouples on the non-exposed surface is above160 ^{o}C+T $_{Ambient}$, T $_{Ambient}$ being the ambient temperature when the product was tested at 11^{o}C.

Figure 3.4(b): Setup of the fire resistance test

Figure 3.4(c): Themodatalogger

3.5 Gantt Chart and Key Milestones

Several key milestones for this research project must be achieved in order to meet the objective of this project. Project gantt chart is divided into two part. First part is for Final Year Project 1, and second part is for Final Year Project 2.

Table 3.5(a): Gantt chart and key milestone of the Final Year Project 1

No	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Literature Review and Methodology														
4	Draft Extended Proposal														
5	Submission of Extended Proposal						☆								
6	Proposal Defense									☆					
7	Prepare Materials and Equipments														
8	Preparation of Plate														
9	Draft Interim Report														
10	Submission of Interim Report														☆

There are three project milestones in Final Year Project 1 which are Submission of Extended Proposal, Proposal Defense and Submission of Interim Report.

Table 3.5(b): Gantt chart and key milestone of the Final Year Project 2

No	Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Fire Resistance Testing														
2	Draft Progress Report														
3	Progress Report Submission							★							
4	Analysis of result & Discussion														
5	Preparation of Pre-SEDEX														
6	Pre-SEDEX / Poster Presentation										★				
7	Draft Technical Report														
8	Technical Report Submission												★		
9	Draft Dissertation														
10	Submission of Dissertation												★		
11	VIVA														★
12	Submission of Hard-Bound Copy of Project Dissertation														★

For Final Year Project 2, project work more focus on the testing and analyzing the data. There are several project milestones in this part which are Pre-SEDEX, Technical Report and Dissertation Submission, VIVA and Hard-bound submission.

3.6 Project Work Flow

Figure 3.6 below shows the work flow of the project:

Problem Statement and Objective of the project

Identifying the purpose of this research project

↓

Literature Review

Gathering as much information as possible from various sources such as journals and websites

↓

Experiment Design

Identifying the specimens that need to be investigated and the experimental procedures

↓

Data Analysis and Interpretation

The findings obtained are analyzed and interpreted critically.

↓

Documentation and Reporting

The whole research project will be documented and reported in detail. Recommendations or aspects that can be further improved in the future will also be discussed.

Figure 3.6: Project Work Flow

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Composites Plates Preparation

Preparation of composite plates has been done according to the steps that have been decided before. The fabrication was done using mold-pour and hand impregnation techniques. Uses of external pressure, heat and vacuum bagging could improve the mechanical properties [25].

Some of the composite plates that have been produced do not have sufficient strength to hold itself and need to reproduce again. The plates produced very fragile and soft. Wood consists of many restrain substances such as hemicelluloses, starches, sugar and phenols. The cement crystallization may be effected by these substances. Figure 4.1 shows all the composite plates that have been produced.

The content of the mixture is also affecting the cohesion of the mixture paste. The higher sawdust content in the mixture reduced the cohesion between the components of the mixture. The workability of the mixture decreased with the increase of sawdust content, though it remained good workability.

After finish fabricates the composite plate, the density of each plate is determined. Table 4.1shows the density of each composite plate produced. Based on the table, all composite plates produced have higher density compared to the wood plate. Based on the density of composite produced without additive, plate C has higher density which is 1.543 g/cm^3 followed by plate A and plate B. Density depend on the sawdust : cement ratio [24]. Higher sawdust content results in a much lighter composite, as shown in table above. Composites with higher contents of cement have higher density compared to others.

By adding additives in the composites mixture, the composite's density becomes slightly changed. Composite with vermiculite, Plate D content has higher density which is1.564 g/cm^3, compared to composite that is produced without it. This is due to high density of vermiculite structure affecting the density of the composite produced. However, composite that is produced with additives of rubber particles has lower density compared to other composites. Since the rubber particles added in the composite has low density, the density of composite produced also has low density.

		
Plate A	Plate B	Plate C

	
Plate D	Plate E

Figure 4.1: Composite plates produced

Table 4.1: Density of Composite Plate

Composite Plate	Density (g/cm^3)
Plate A	1.128
Plate B	0.952
Plate C	1.473
Plate D	1.764
Plate E	0.985
Wood Plate	0.912

4.2 Fire Resistance Test

All plates have been test according to the procedure that has been mentioned before. The temperature rises on the unexposed surface has been recorded and plotted on the temperature vs. time graph. The experimental results of the fire resistance test of each plate are summarized in Figure 4.2.

All the specimens tested shown a different behavior when exposed to heat. Wood plate shows much better insulating behavior compared to composite plates. The temperature curve of wood plate in the unexposed side shows that during the first 15 minutes of the test, the temperature does not vary which is in range of 34 ^{o}C – 36 ^{o}C. This is due to the thermal wave generated on the exposed side take time to penetrate the plate. The temperature at the unexposed side begins to increase dramatically after 15 minutes of the test. The temperature rises from 36 ^{o}C to 93 ^{o}C at rate of 5.18 ^{o}C m^{-1} for 10 minutes. Then, the temperature constant at range of 92 ^{o}C - 95 ^{o}C for at least 35 minutes until the fire test ended.

During the fire test, char layer formation can be observed on the wood surface after 5 minutes of the test. When wood is heated above 280 ^{o}C, it will cause decomposition of wood or pyrolysis. Pyrolysis is a thermal decomposition of a wood in the absence of oxygen converting it to gases, tar and charcoal [26]. Char layer forms on the surface of wood when exposed to fire. Char need high temperature for its consumption. It protects the underlying layers of the wood from the action of flame due to its high thermal resistance [27]. That is the reason why the temperature on the unexposed surface of the wood plate constant at certain temperature for long time duration. This shows that wood has a good fire resistant ability compared to other materials.

The composite plates tested shown a different behavior. The temperature curves of Plate A, B, C, D and E during the first 8 minutes of the test are similar with the curve of wood plate which are shown that the temperature does not vary in the unexposed side. This is due to the time of the thermal wave generated on one side takes to get exposed to other side is varies according to the moisture content of the plate. From this moment, the temperature starts to increase linearly according to the composition of the plate. The temperature curve of Plate A which is a control specimen show that the temperature start to increase after 9 minutes of the test at rate of 6.3 $^{o}C\ m^{-1}$ for 22 minutes duration. After this moment, the temperature remains constant at range of 174 ^{o}C to 178 ^{o}C. The highest temperature recorded for plate A is 178.7 ^{o}C.

The temperature curve of plate B after 8 minutes of the test is different compared to plate A. After 5 minutes of the test, the temperature begins to rise rapidly from 37.7 ^{o}C to 185.3 ^{o}C in 20 minutes (7.38 $^{o}C\ m^{-1}$). After that the temperature remains constant for 18 minutes before it increases again until the highest temperature recorded which is 221^{o}C.

The temperature curve of plate C is slightly better compared to plate A and B. The temperature starts to rise after 10 minutes of the test from 34.8 ^{o}C to 165.4 ^{o}C in 23 minutes (5.67 $^{o}C\ m^{-1}$). Then the temperature remains at constant in range of 164 ^{o}C to 168 ^{o}C. The highest temperature reached is 168.7 ^{o}C.

After the composite plate is heated for 8 minutes, the temperature begins to increase. This is associated with the heat transfer by conduction through the solid [8]. The temperature begins to rise due to free water evaporation in the plate and at this point the composite start to undergo loss in mass [27] [28].

Based on the results of the fire test, it shows that the relative amounts of binder (inorganic matrix) and filler (sawdust) strongly affected the temperature curve on the unexposed side. Composite with high cement contents shows a better fire resistance behavior. The temperature reach at the unexposed side by the composite with high cement contents also lower compared to other composite.

As for the composite with vermiculite additive, the temperature curve recorded almost similar with the composite without it. The improvement in the thermal behavior is not very significant compared to the thermal behavior of composite with rubber powder additive. Vermiculite is used to prolonged fire resistance behavior of composite at temperature above 1000 ^{o}C [29]. Therefore, the effects of adding vermiculite on the material can only be seen at higher temperature that was not measured in this study. The fire resistance behavior of the composite changes when rubber particles are added in the composition. The rate of temperature rise decreased when rubber particles were added. This is because rubber takes time to be decomposed when heated [31]. When the composite is exposed to high temperature after a few minutes, the rubber particles get burnt and left a small hole on the composite surface.

During this fire resistance test, there are no smoke releases when the composites where subjected to fire except for wood and plate E. Plate E releases black smoke when exposed fire for the first 15 minutes of the test. This is due to rubber particles content in the composite. Smoke produced when rubber gets burnt. The composite is exposed to high temperature, some changes in color occur. For first 30 minutes, the composite color did no change. After about 40 minutes of the test, the color of the composite starts to change from yellow –grayish color to white-grayish color.

Based on the test results carried out from this research, it is found that composite with sawdust as filler are suitable to replace the used of wood in the fire door making. Composite has lower fire resistance compared to original wood. The rate of temperature rise of the composite is almost similar to wood but the temperature reached at the unexposed side is almost twice compared to the original wood.

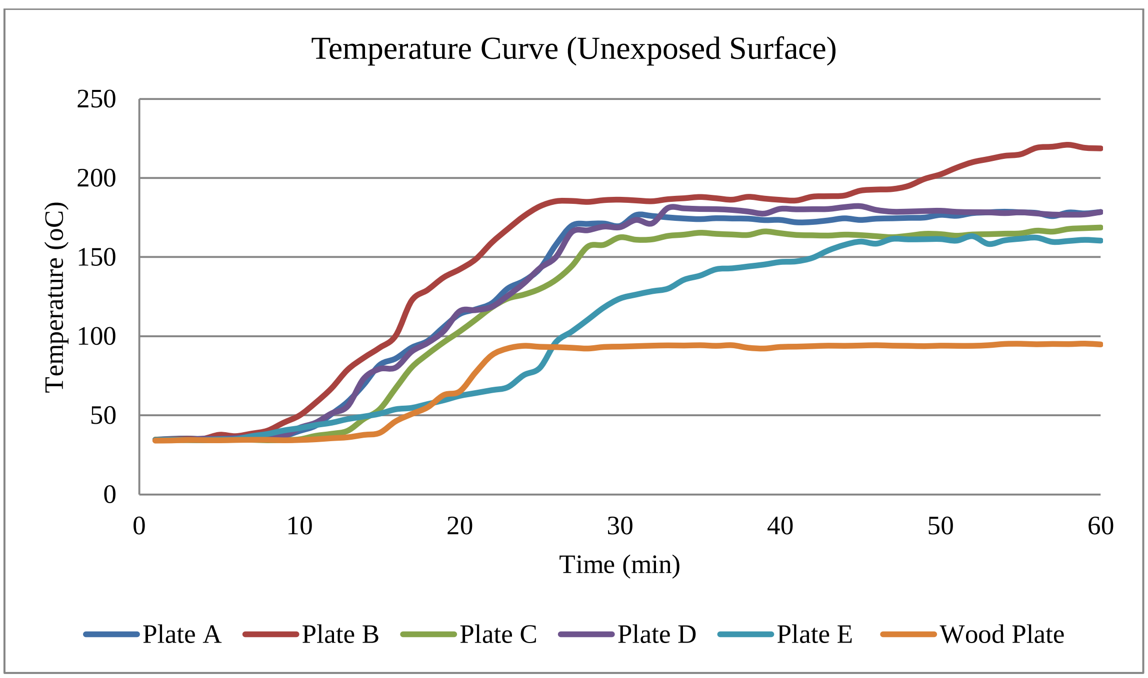

Figure 4.2(a): Temperature changes on the non-exposed surface of each plate

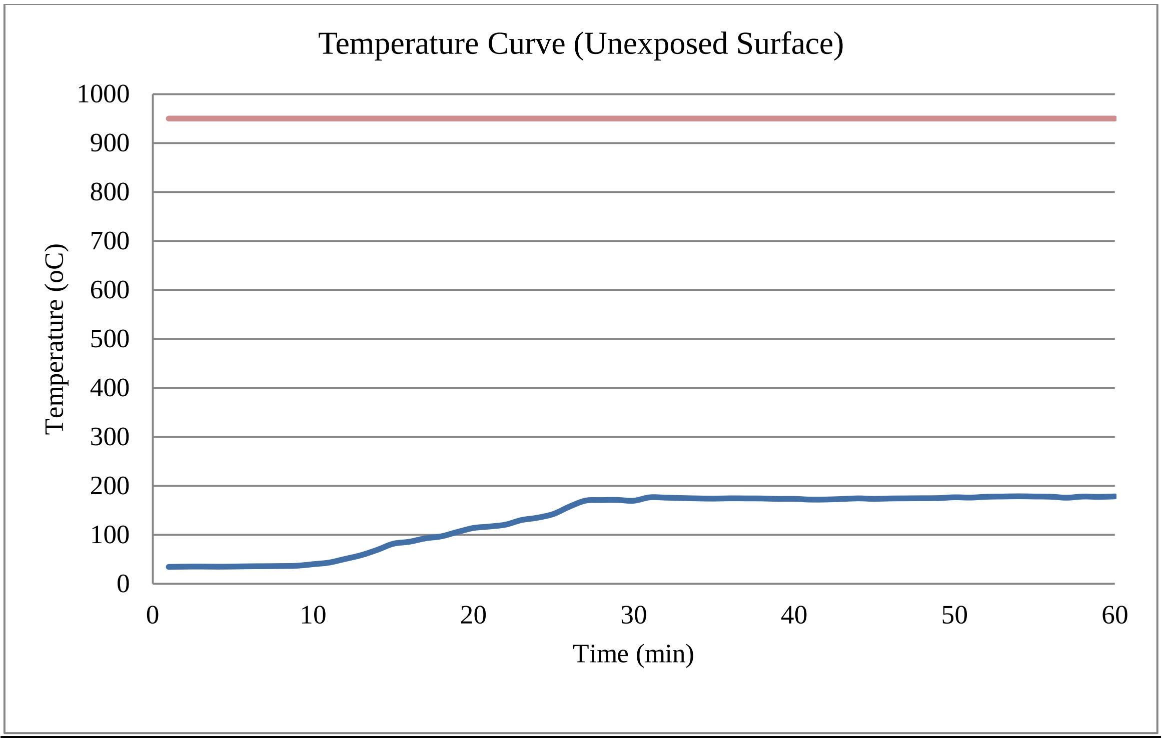

Figure 4.2(b): Temperature changes on the non-exposed surface of Plate A

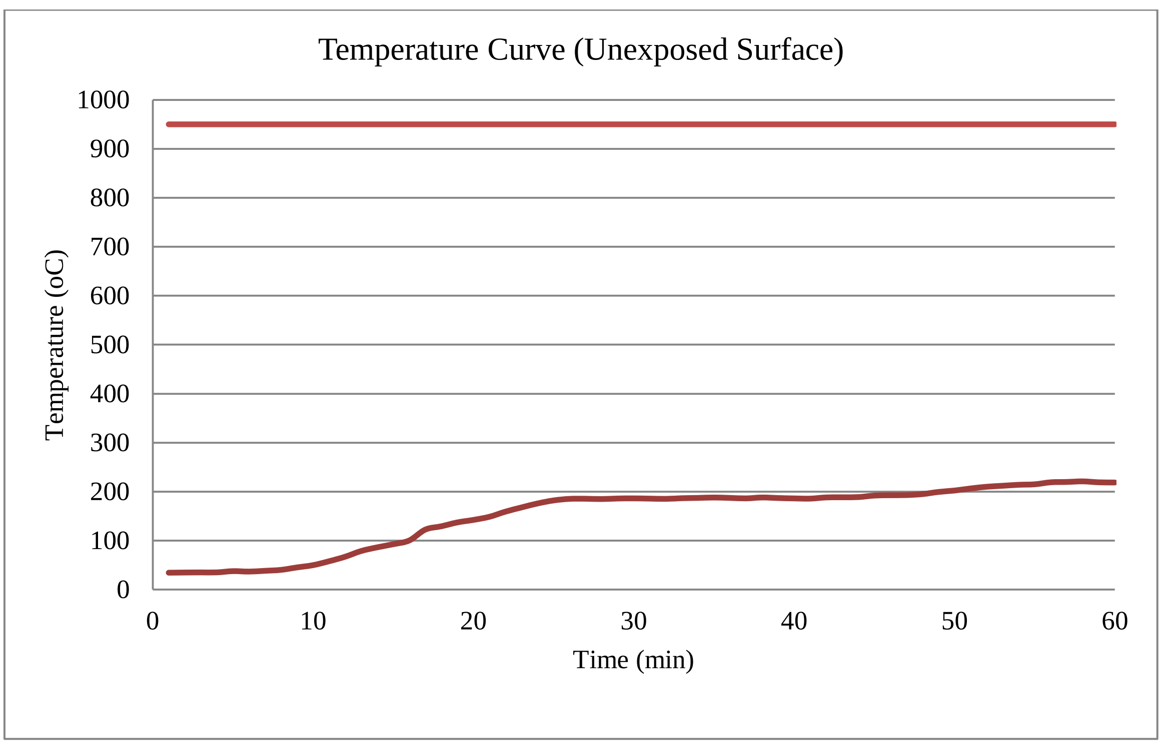

Figure 4.2(c): Temperature changes on the non-exposed surface of Plate B

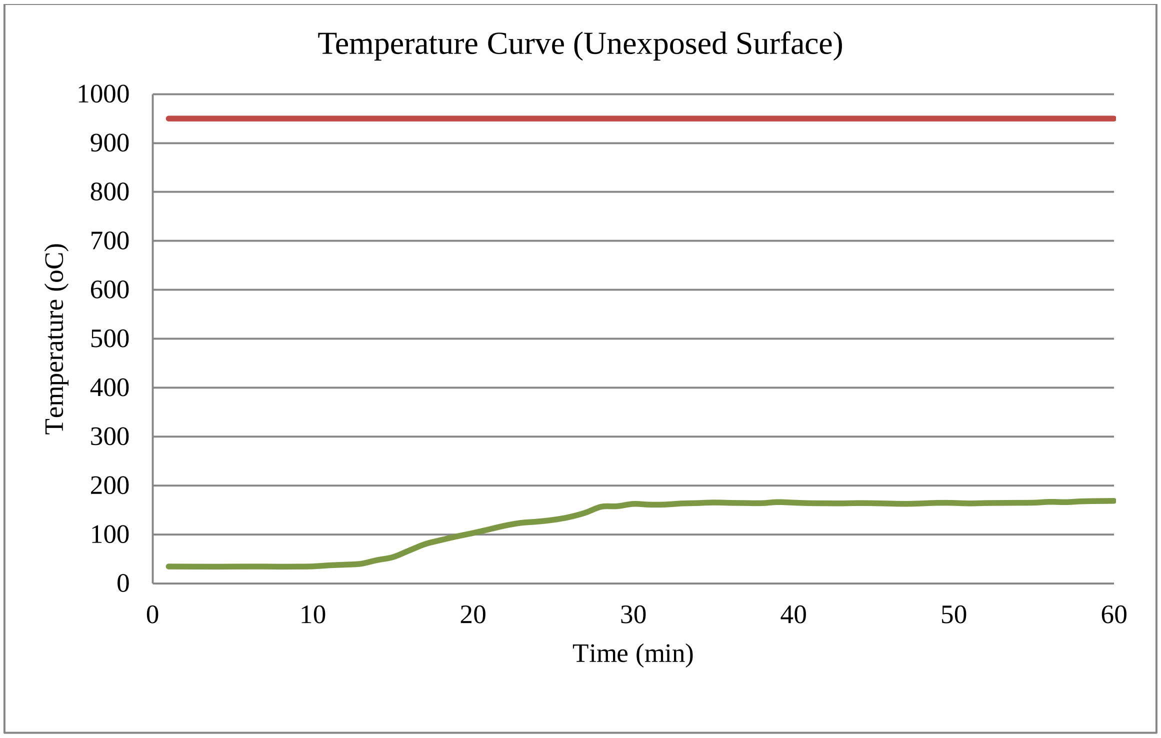

Figure 4.2(d): Temperature changes on the non-exposed surface of Plate C

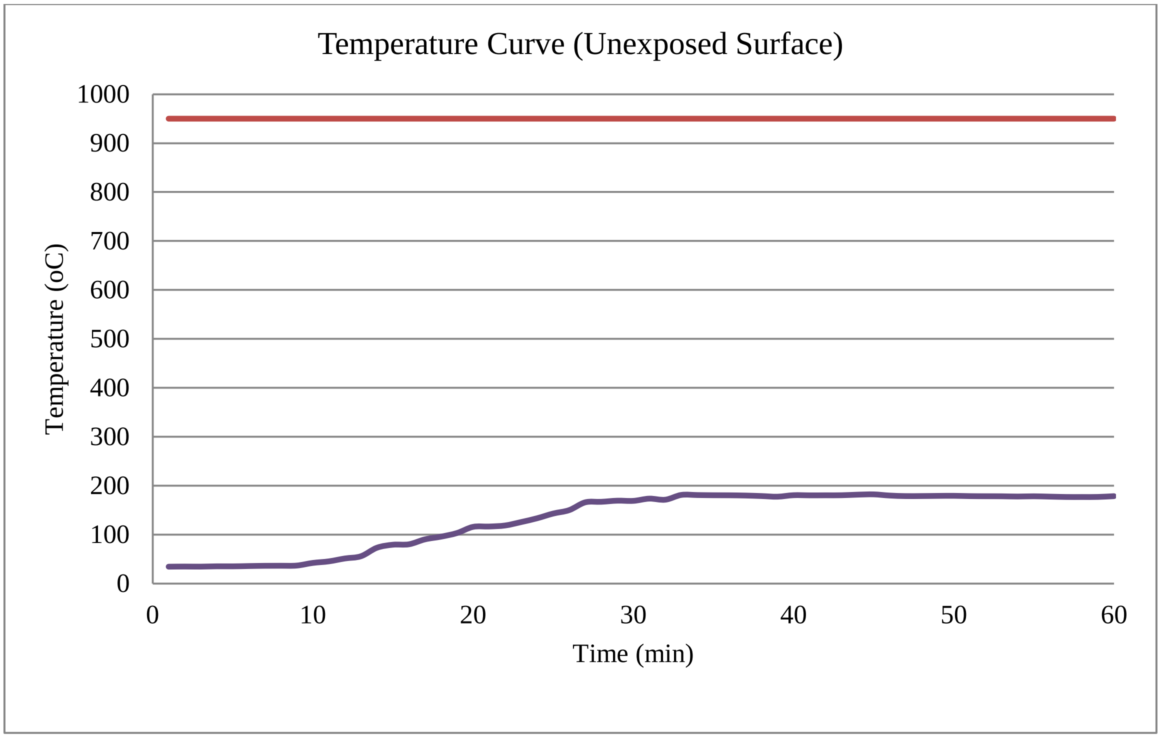

Figure 4.2(e): Temperature changes on the non-exposed surface of Plate D

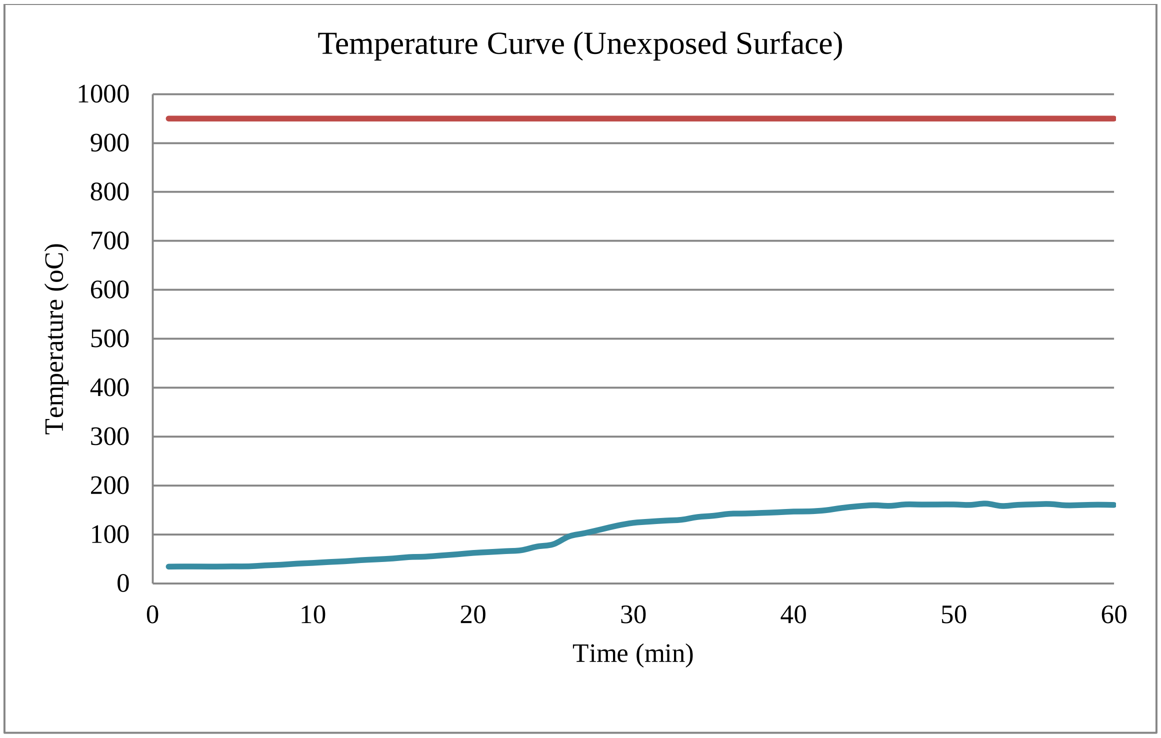

Figure 4.2(f): Temperature changes on the non-exposed surface of Plate E

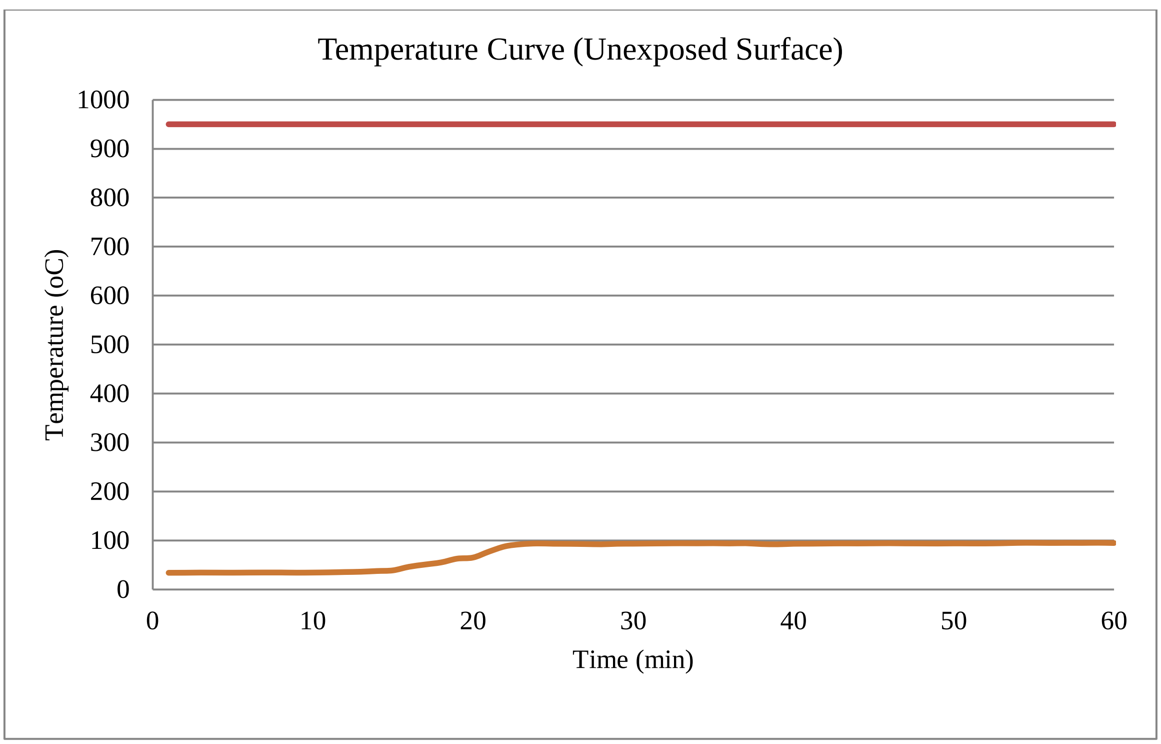

Figure 4.2(g): Temperature changes on the non-exposed surface of Wood Plate

CHAPTER 5
CONCLUSION AND RECOMMENDATION

As for conclusion, based on this research, it is found that composite material with sawdust as filler is suitable to replace the uses of wood in fire door making. The fire resistance of composite is lower compared to original wood. Fabrications of composite plates were made by mixing inorganic binder, Portland cement and waste sawdust. Fabrication was conducted without using any specialized equipment such as external pressure, air vacuum or applied heat. The composite plates produced have a slightly higher density compared to original wood plate.

Fire resistance test also have been done to the composite plate to study the temperature rise on the unexposed surface. The composite pates were heat at constant temperature of 950 ^{o}C for 60 minutes duration. Based on the test results, several conclusions can be made:

- Increasing the inorganic binder content reduces the rate of temperature rise and temperature reach on the unexposed surface.
- Additions of vermiculite and rubber particle slightly improve the fire resistance of the composite plate but not as good as the original wood.

As for recommendation, more researches need to be done on another possible waste that can be used to replace uses of wood in fire door making for example rice husk and rattan. Another type of additive also should be studied in order to improve the fire resistance properties of the composite to be similar with the original wood.

REFERENCES

1. Diong, C.K, *An issue of Maintenance from the Technical and Legal perspective* Technical Director, Noval Technology S/B, 2002: p. 1.
2. Rakic J, *Fire resistant doors and shutters*. Alliance for Fire & Smoke Containment (PFPA), 2005: p. 1.
3. Digest BRE, *Fire pack.* 2011, BREPress: p. 963
4. Fire Resistance Requirements in Australia. EWPAA 2009, Australia. p. 3.
5. Chow, W.K., Chan, Y.Y, *Computer Simulation of the Thermal Fire Resistance of Building Materials and Structural Elements.* In Department of Building Services Engineering. 1994, The Hong Kong Polytechnic University.
6. Robert, H.W, *SFPE Handbook of Fire Protection Engineering.* Forth ed. 2008, Massachusetts: Omegatype Typography, Inc.
7. Lie, T.T., *A Method for Assessing the Fire Resistance of Laminated Timber Beams and Columns*. Canadian Journal of Civil Engineering, 4, p. 161 (1977).
8. James, G., Christos, P., Balaguru, P., *Fire Resistance of Inorganic Sawdust Biocomposite.* Department of Civil, Architectural, and Environmental Engineering. 2007, University of Massachusetts Dartmouth.
9. American Society for Testing and Materials. *Standard test method for heat and visible smoke release rates for materials and products* – ASTM test method E906 . In: Annual Book of ASTM Standards, vol. 4.07, West Conshohocken. (PA): ASTM International; 2006. p. 26.
10. Sorathia U, Ohlemiller T, Lyon R, Riffle J, Schultz N. *Gap analysis for durability of fiber reinforced polymer composites in civil infrastructure*. Reston, VA: American Society of Civil Engineering, Civil Engineering Research Foundation; 2001.
11. American Society for Testing and Materials. *Standard terminology of fire standards* – ASTM specification E176. In: Annual Book of ASTM Standards, vol. 4.07, West Conshohocken, Pennsylvania: ASTM International; 2001. p. 651-65.

12. Federal Aviation Administration and Department of Transportation. *Aircraft materials fire test handbook.* Office of Aviation Research, Washington, DC: 2000
13. Harper, A. *Handbook of Building Materials For Fire Protection.* United State: McGraw-Hill 2004
14. Lennon, T. *Structural Fire Engineering.* Willoughby Road, Bracknell: ICE Publishing 2011
15. English B. *Wastes into wood: composites are a promising new resource*. Environ Health Persp 1994;102(2):168-70
16. Stark NM. *Wood fiber derived from scrap pallets used in polypropylene composites*. Forest Prod J 1999;49(6):39-48
17. Horrocks, A. R. and Price, D. *Advances in fire retardant materials.* Great Abington, Cambridge: Woodhead Publishing Limited 2008
18. Sorfa, P. *Properties of wood cement composites,* Journal of Applied Science 1984
19. Dinwoodie, J.M. and Paxton, B.H. *A technical assessment of cement-bonded particleboard, in Proceeding 1st Inorganic Bonded Fiber Composites Symposium, In: A.A. Moslemi,* (ed) Forest Products Research Society 1989
20. EN 1363-1, Fire Resistance test, Part 1: General requirements, 2000
21. James, G., Christos, P., Balaguru, P., *Mechanical Behavior of Fire-resistant Biocomposite.* Department of Civil, Architectural, and Environmental Engineering. 2008, University of Massachusetts Dartmouth.
22. Perez, S.M., Gazquez, M.J, Barneto. A.G, and Bolivar, J.P. *Thermal Characterization of New Fire-insulating Materials from Industrial inorganic* Tio_2 *Wastes*. Department of Applied Physics, November 2012, University of Huelva, Huelva, Spain
23. Turgut, P. *Cement composites with limestone dust and different grades of wood sawdust*. Department of Civil Engineering, November 2007, Harran University, Osmanbey Campus, Sanliurfa, Turkey.

24. Zziwa, A., Kizito,S. and Banana, A.Y. *Production of composite brick from sawdust using Portland cement as binder*. Department of Forest Products Engineering, Makerere Univensity, June 2006, Kampala, Uganda.
25. Xiaoli, G., Xu , M. and Lixian, L. *Pyrolysis of poplar wood sawdust by TG-FTIR and Py–GC/MS*, College of Chemical Engineering, Nanjing Forestry University, July 2013, Guangzhou, China.
26. Lizhong, Y., Yupeng, Z,. and Yafei, W. *Predicting charring rate of woods exposed to time-increasing and constant heat fluxes*. State Key Laboratory of Fire Science, University of Science and Technology of China, January 2008, Hefei, Anhui Province, China.
27. Ergun, A., Gokhan, K., and Serhat, M., *The effect of cement dosage on mechanical properties of concrete exposed to high temperature*, Technical Education Faculty, Construction Department, August 2010, Afynkarahisar, Turkey.
28. Dorez, G., Taguet, A., and Ferry, L. *Thermal and fire behavior of natural fibers/PBS biocomposites*. Centre de Recherche CMGD, June 2012, Cedex, France.
29. R. Kozlowskia, B. Mieleniaka, R. Fiedorowb, K. Bujnowicza. *Light rigid fire blockers.* Institute of Natural Fibres, Wojska Polskiego, August 2004, Poznan, Poland.
30. Venkatesh K.R., Luke A. Bisby, and Mark F. *Green. Experimental evaluation of the fire behaviour of insulated fibre-reinforced-polymer-strengthened reinforced concrete columns.* Department of Civil and Environmental Engineering, Michigan State University, June 2005, East MI, USA.
31. J. Haydary, Z. Koreňová, Ľ. Jelemenský, J. Markoš. *Thermal decomposition of waste polymers*. Institute of Chemical and Environmental Engineering, Faculty of Chemical and Food Technology, Slovak University of Technology, Radlinského, October 2008, Bratislava

APPENDIX A

Table Appendix A: Data of Temperature Changes on Unexposed Surface Plate

Time (min)	Temperature Changes on Unexposed Surface (^oC)					
	Plate C	Plate D	Plate E	Plate F	Plate G	Wood Plate
1	34.6	34.5	34.6	34.4	34.3	34
2	35.1	34.9	34.4	34.7	34.6	34.1
3	35.3	35.1	34.3	34.5	34.5	34.4
4	35	35.2	34.2	35.2	34.4	34.3
5	35.3	37.7	34.4	35.1	34.8	34.2
6	35.8	36.8	34.5	35.7	34.9	34.4
7	36	38.4	34.5	36.2	36.8	34.5
8	36.3	40.3	34.2	36.3	38.2	34.5
9	36.9	45.3	34.4	36.7	40.4	34.2
10	40.1	49.9	34.8	42.1	41.9	34.4
11	43.4	57.9	37	45.3	43.8	34.8
12	50.8	67.1	38.3	51.2	45.3	35.5
13	58.5	78.8	40.2	55.7	47.6	36.1
14	69.3	86.3	47.6	73.1	49.2	37.6
15	81.8	92.7	53.8	79.3	51	38.9
16	85.9	100.3	67.1	80.2	53.8	46.2
17	92.8	122.5	80.3	90.3	54.7	50.8
18	97	129.3	88.7	95.8	57.1	55.1
19	105.8	137.2	96.2	103.2	59.5	62.8
20	114	142.3	103	115.8	62.3	65.1
21	117	148.7	110.5	116.5	64.1	77.3
22	120.8	159.2	118.2	118.6	65.9	88
23	130.2	167.8	123.8	125.6	67.8	92.3
24	135	175.9	126.3	133.4	75.4	93.9
25	142.7	182.1	129.9	143	80	93.3
26	157.8	185.3	135.6	150	96.2	93.1
27	169.9	185.5	144.4	165.9	103	92.7
28	171	184.9	156.7	167	110.5	92.2
29	171.2	186	157.8	169.3	118.2	93.2
30	169.7	186.3	162.5	168.9	123.8	93.4
31	176.6	185.8	161	173.5	126.3	93.7
32	176	185.3	161.2	171.3	128.4	94
33	175.1	186.6	163.4	181.1	130.1	94.2
34	174.4	187.2	164.2	180.8	135.7	94.1
35	174	188	165.4	180.4	138.3	94.3

36	174.6	187.2	164.7	180.3	142.3	93.9
37	174.4	186.3	164.3	179.8	142.9	94.3
38	174.3	188.1	164	178.8	144.1	92.7
39	173.4	187	166.2	177.5	145.3	92.2
40	173.5	186.2	165.1	180.5	146.9	93.2
41	172	185.8	164	180.2	147.3	93.4
42	172.2	188.2	163.8	180.3	149.5	93.7
43	173.2	188.5	163.6	180.4	154.2	94
44	174.5	188.9	164.2	181.6	157.7	93.9
45	173.5	192	163.9	182.2	159.8	94.1
46	174.3	192.7	163.2	179.8	158.5	94.3
47	174.5	193	162.6	178.7	161.5	94
48	174.8	195	163.5	178.8	161.2	93.9
49	175	199.4	164.7	179.1	161.3	93.7
50	176.7	202.3	164.5	179.3	161.4	94
51	176.1	206.5	163.5	178.6	160.4	93.9
52	177.8	210	164.3	178.4	163.2	93.9
53	178.3	212	164.5	178.3	158.3	94.3
54	178.7	214	164.8	177.8	160.6	95.1
55	178.3	215	165	178.3	161.6	95.2
56	177.9	219.1	166.7	177.6	162.3	94.9
57	175.9	219.8	166.1	176.9	159.6	95.1
58	178.2	221	167.8	176.8	160.2	95
59	177.6	219.1	168.3	177	160.9	95.3
60	178.5	218.7	168.7	178.5	160.4	94.8

APPENDIX B

Figure Appendix B(a): Sample of sawdust used

Figure Appendix B(b): Portland Cement used

Figure Appendix B(c): Sample of vermiculite powder used

Figure Appendix B(d): Sample of rubber powder used

Figure Appendix B(d): Work frame used

Figure Appendix B(e): Process of making frame

Figure Appendix B(f): Plate A

Figure Appendix B(g): Plate B

Figure Appendix B(h): Plate C

Figure Appendix B(k): Plate D

Figure Appendix B(l): Plate E

Figure Appendix B(m): Wood Plate

APPENDIX C

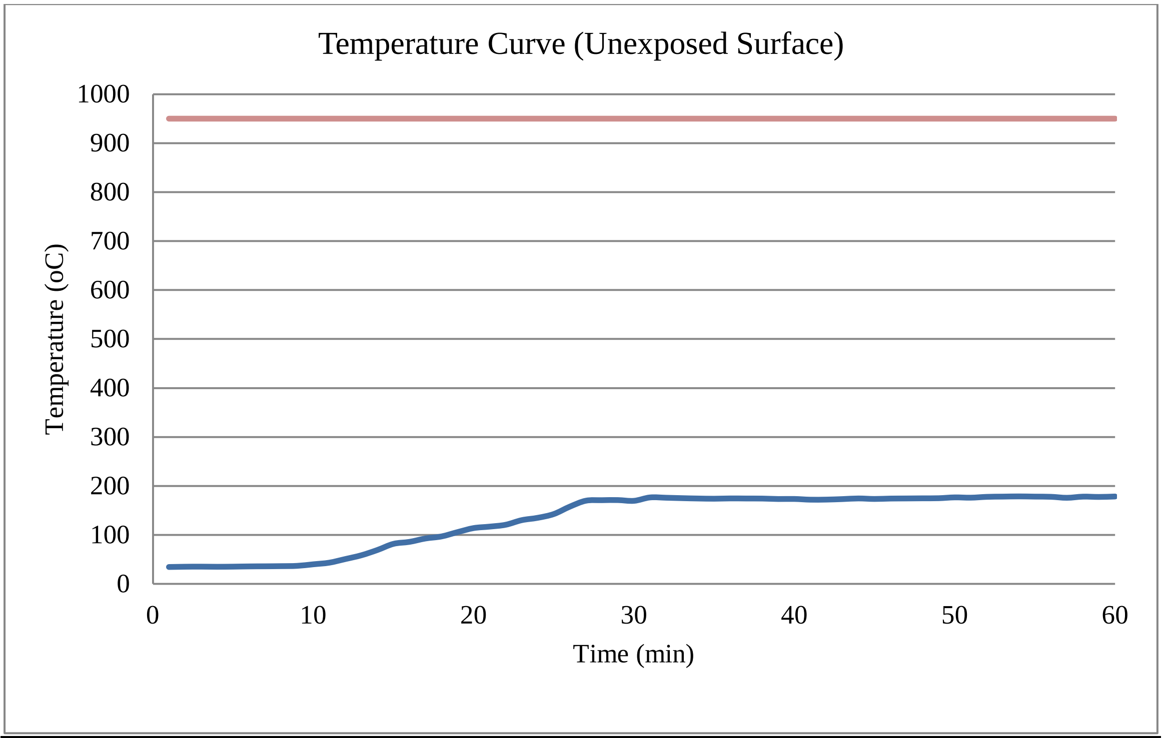

Figure Appendix C(a): Temperature changes on the non-exposed surface of Plate A

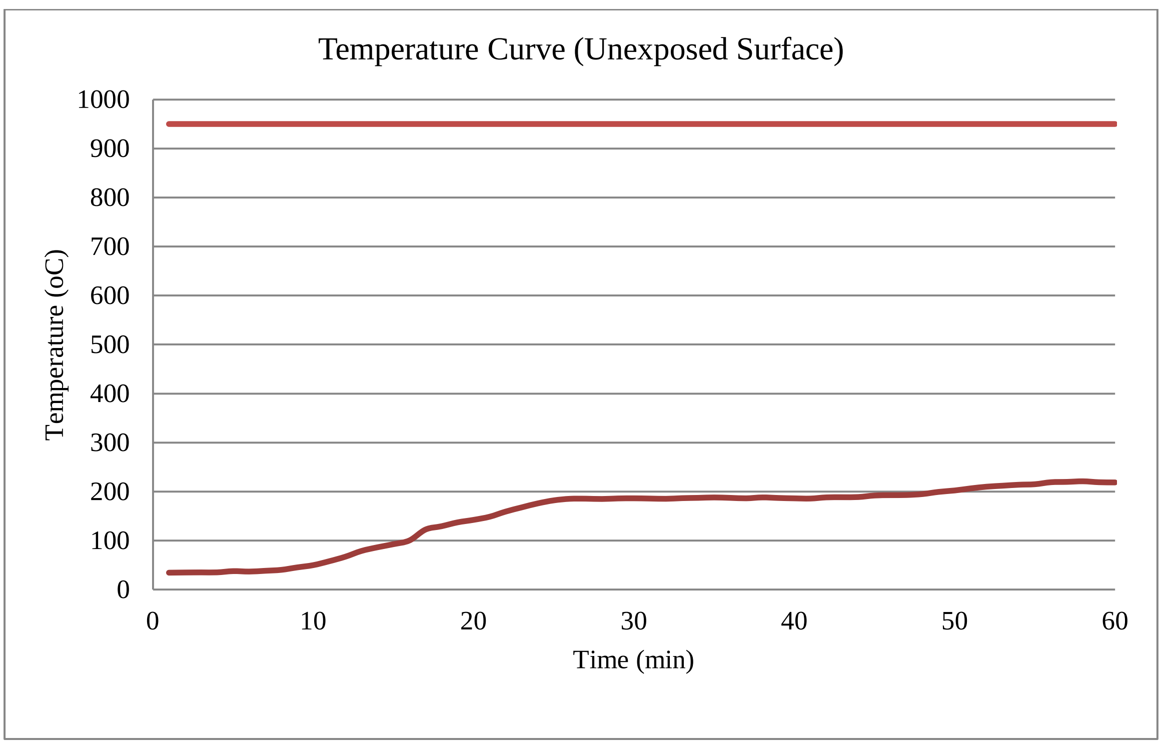

Figure Appendix C(b): Temperature changes on the non-exposed surface of Plate B

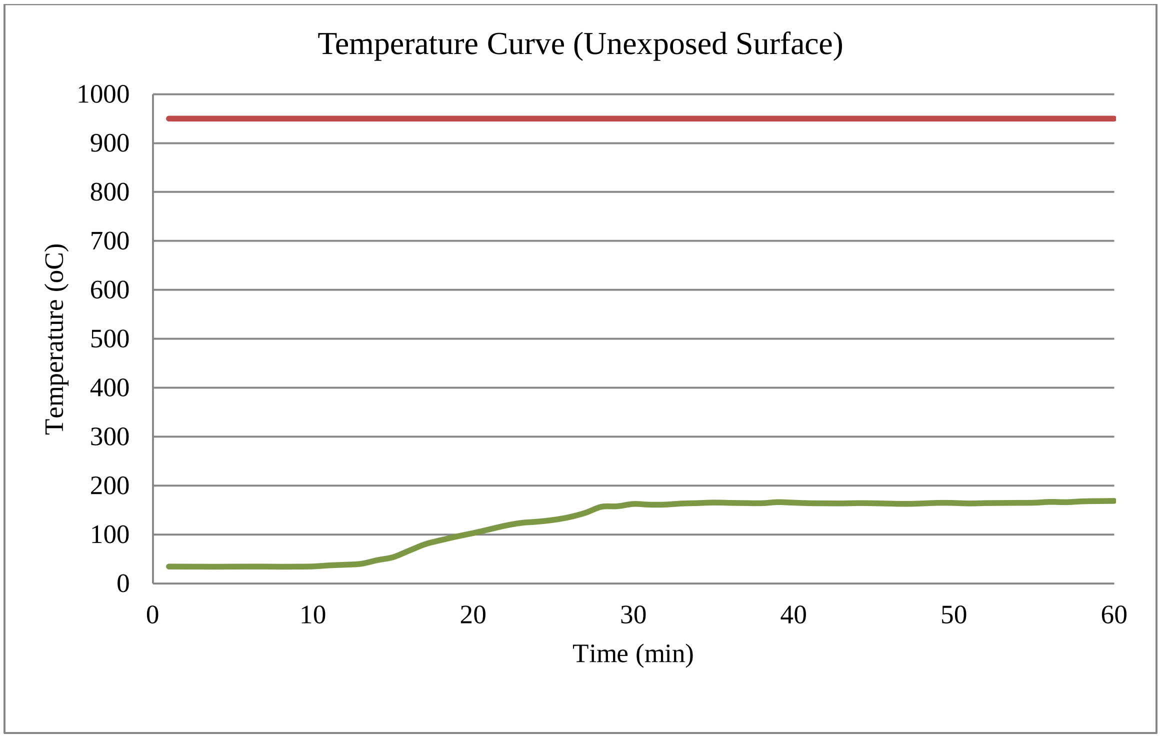

Figure Appendix C(c): Temperature changes on the non-exposed surface of Plate C

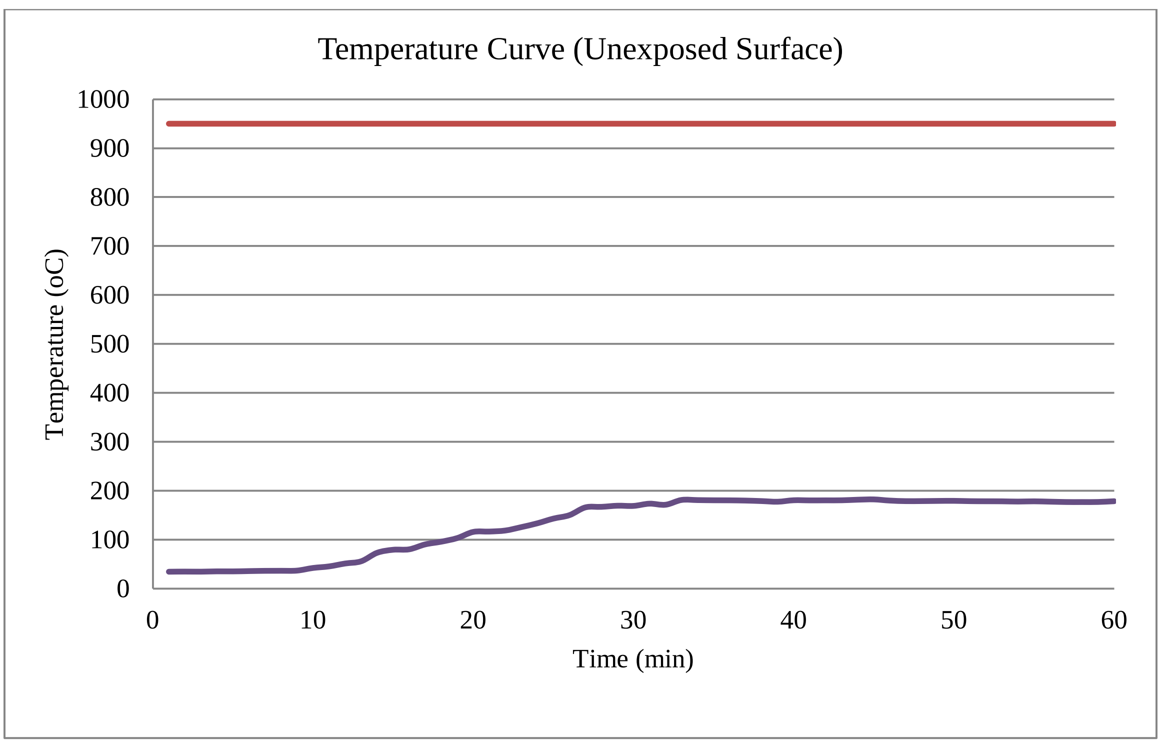

Figure Appendix C(d): Temperature changes on the non-exposed surface of Plate D

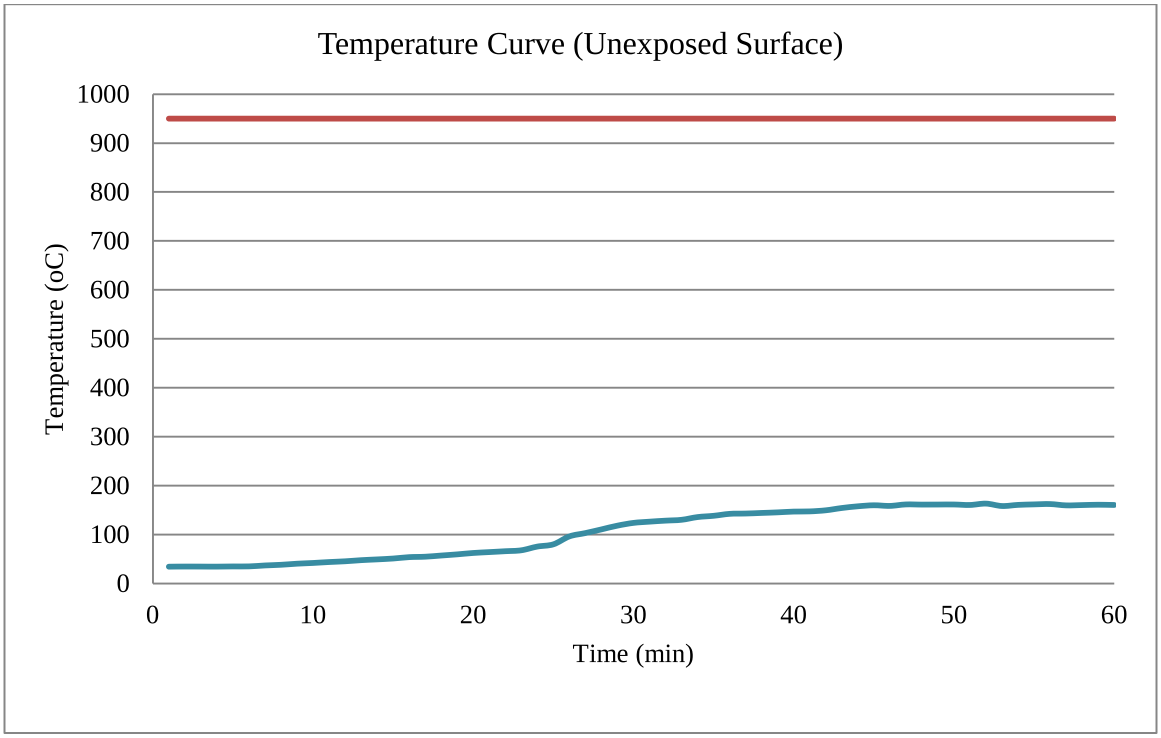

Figure Appendix C(e): Temperature changes on the non-exposed surface of Plate E

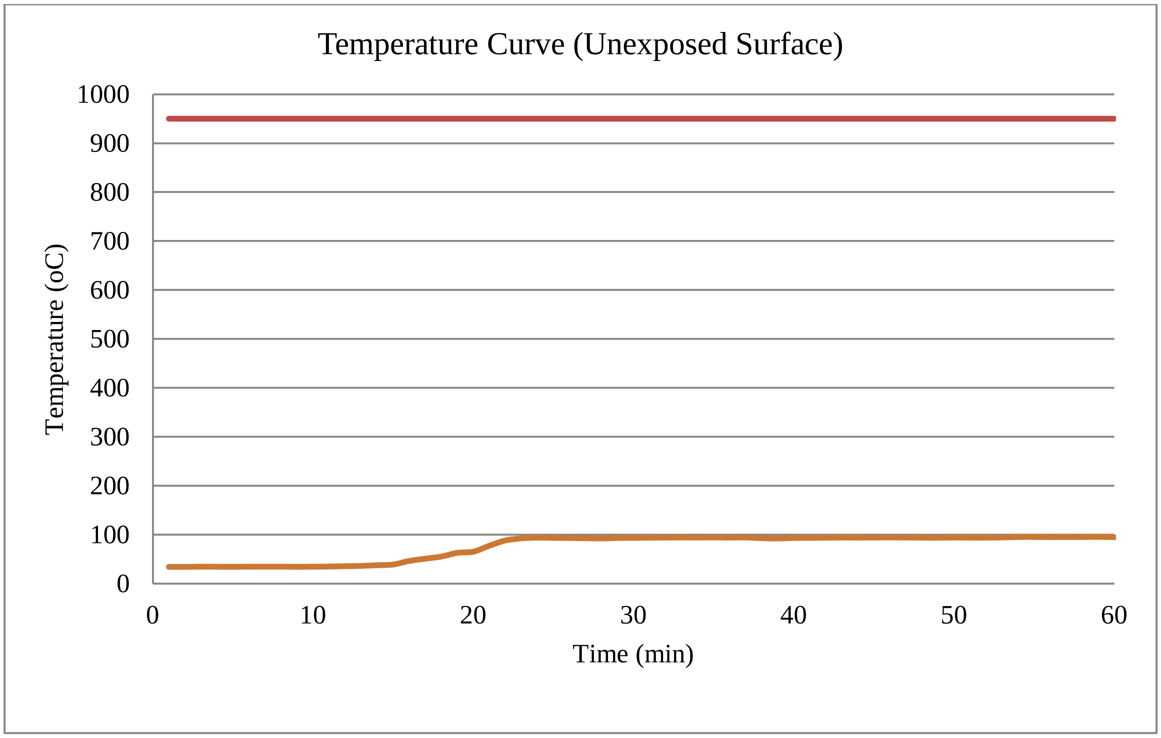

Figure Appendix C(f): Temperature changes on the non-exposed surface of Wood Plate